ARMORED MEDICAL RESEARCH LABORATORY

FORT KNOX, KENTUCKY

PROJECT NO. 5 - CREW FATIGUE RESEARCH

Final Report On

Project No. 5-13, Appraisal of Kind and Degree of Physical Effort
Required of Tank Crews in Relation to Fatigue

Project No. 5-13

24 March 1945

ARMORED MEDICAL RESEARCH LABORATORY
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1. PROJECT: Final Report on Project No. 5-13, Appraisal of Kind and Degree of Physical Effort Required of Tank Crews in Relation to Fatigue.

a. Authority: Letter Commanding General, Headquarters Armored Force, Fort Knox, Kentucky, File 400.112/6 GNOHD, dated 24 September 1942.

b. Purpose: (1) To determine the work rates of tank crew members for various tasks in tanks M4A3, M5, M24 and T23. (2) To demonstrate the reduction of work load and fatigue accomplished by changes in tank design and (3) To indicate the relationship of work rate to the physiological heat load in hot climates.

2. DISCUSSION:

The major problems with which this report deals are (1) tank crew fatigue occurring under all conditions and (2) the impairment of efficiency and morale and the occurrence of heat exhaustion among crews operating in tropical climates.

The work rates determined in this report are of sufficient magnitude to constitute, at times, a cause of crew fatigue when in combination with the many other adverse conditions which surround tank warfare. Much muscular effort is dissipated within tanks because the structural and operational features of tanks have not been designed for maximum ease and efficiency of operation. Observation of crews at work and determination of work rates for the same task in different tank models gives some lead as to the amount of energy wasted because of imperfect tank design. If ease of crew operation is created without impairment of mechanical operation, as has been done in certain cases, the sparing of physical effort should result in lessened crew fatigue and better performance.

Efficiency and morale deteriorate and heat exhaustion finally sets in when the physiological heat load of an individual becomes too great. This heat load arises (1) from exposure to an environment which prevents adequate body cooling, and (2) from excessive body heat production. The latter is largely a result of muscular effort and is directly proportional to the work rate. The work rates in this report indicate the relative contribution of various tasks within tanks to the heat load of the crew members. Comparative rates for the same task in different tanks show how improvements in design have lowered heat production. Any such reduction will improve performance in severe climatic heat and humidity.

The work rates were determined by the oxygen consumption method

for individual crew members of the tanks M4A3, M5, M24 and T23. Nineteen tank crew members were used as subjects. Tests were carried out in the field under conditions resembling, insofar as possible, combat situations. The results, because of many experimental limitations permit only estimates of work rates as they actually exist.

3. CONCLUSIONS:

a. The work rates of tank crew members make a significant contribution to fatigue under combat conditions and to the heat load in hot climates. See Appendix A for detailed description, and Charts 1, 2, 3, 4 and 8 for numerical summary of rates.

b. Comparative work rates and performance demonstrate that changes in tank design can and do effect a significant lowering of work rate and heat load without any loss of mechanical operating efficiency (Appendix B).

c. Continued reduction in work rates through improved tank design will reduce crew fatigue under all conditions and will increase tolerance to hot environments. Better military performance should result.

4. RECOMMENDATIONS:

a. Agencies and individuals concerned in tank design should consider crew function and crew work rates in original design and continue efforts to render work within tanks more efficient and easy.

b. Agencies and individuals concerned in the design and testing of clothing and equipment for tank crews should take cognizance of the work rates or endogenous heat production of the crew members.

NOTE: The recommendations as set forth in this project have been concurred in by Col. Fred W. Makinney, Chief of Staff, Armored Center.

Submitted by:

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APPENDIX A

DETAILS OF TESTS AND RESULTS

1. The selection of subjects:

Nineteen (19) tank crew members were used as subjects in these tests. Except for three men, they were chosen for experience* in the task for which the test was to be run. It was apparent early that inexperience led to slow and faulty performance and yielded higher rates of work.

2. Procedure:

Work rate was determined by the oxygen consumption method. The subjects breathed through a respiratory valve offering minimum resistance and attached to the helmet where it interfered least with muscular movement. For the earlier tests a standard Rudolf valve was used, but subsequently a light all plastic valve proved superior. Before all determinations the subjects had had considerable experience, under a variety of circumstances, in respiring through the valve, and in all studies except loading, a dry run was made immediately before the actual test.

Expired air was collected in 120 liter Douglas bags, the number of bags used depending on the activity tested. Collections were made with the subject in a steady state; or if a steady state could not be attained the oxygen debt was determined and the activity metabolism calculated. The length of periods varied from 5 to 40 minutes (see description of separate tests). The bags were carried either inside or outside the tank and the expired air was led to them through 1¼" smooth bore rubber tubing. This was manipulated by an observer in some cases to minimize interference with the subject's activity. Duplicate oxygen and CO_2 analyses were run on each collection.

3. The expression of results:

The results are expressed as Cals/hr, Cals/m^2/hr, Cals/kg and Cals above resting. Cals above resting is the total work rate minus the resting metabolic rate and indicates the load of the task per se.

Each test is described in detail in the ensuing section. Charts 1, 2, 3, and 4 summarize all data and give values for individual runs.

4. Analysis of the work loads of crew members:

The major work loads of individual crew members are listed below.

*"Experienced" driver indicates having driven for at least 1 year or through maneuvers. "Experienced" loader indicates having loaded at least 200 rds.

a. Tank Commander:

(1) Standing (at times moving over rough terrain).

(2) Operation of the 50 cal. AA machine gun.

b. Gunner:

(1) Sitting (at times moving over rough terrain).

(2) Many tasks of minor energy requirement, such as sighting on a target*, gun inspection and maintenance.

(3) (In the M4A3 tank, moving rounds from the right turret ammunition bins to the ready racks or to the loader.)

c. Loader:

(1) Sitting (at times moving over rough terrain).

(2) Loading the main gun.

(3) Moving rounds to the ready position.

(4) Servicing and cleaning the 30 cal. machine gun.

d. Assistant driver:

(1) Sitting (at times moving over rough terrain).

(2) Operating the 30 cal. machine gun.

(3) (In the M4A3 tank, passing rounds into the turret from the rack beneath the turret basket.)

(4) (In the T23, M5 and M24 occasional driving, using the dual controls.)

e. Driver:

(1) Sitting in the moving tank.

(2) Driving.

5. Description of tests and results:

a. Basal Metabolism: The subjects had not eaten for the period of 14 hours. They slept overnight in the laboratory, and were awakened just before the tests were made.

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* Verbal reports from tank gunners returned from combat indicate that the power traverse is used except for minor adjustments.

Average results of 25 tests:

CALS/HR	CALS/M^2/HR	CALS/KG	% NORMAL BMR
69	37	1.0	-3

No. of subjects: 18 Test period: 8-16 mins.

b. Resting Metabolism: Except for three (3) subjects, two or more determinations were made of the resting metabolism of each man. The subjects were seated quietly throughout the test. No attempt was made to standardize the conditions with respect to time of day, previous activity, or ingestion of food.

Average results of 35 tests:

CALS/HR	CALS/M^2/HR	CALS/KG
90	50	1.2

No. of subjects: 19
Test period: 8-12 mins.

c. Seated in a tank moving over rough terrain: A large part of a tank crew's activity consists of sitting in a moving tank. If the terrain is rough, muscular effort is required in balancing and holding on.

The tests were conducted in the buttoned M4A3 tank with the subject seated in either the gunner's or loader's position watching through the periscope. The ride was moderately rough over cross country terrain. Over smoother terrain the values should approach the resting metabolism.

Average results of four tests:

CALS/HR	CALS/M^2/HR	CALS/KG	CALS ABOVE RESTING*
120	60	1.7	25

No. of subjects: 3 Test period: 8-10 mins.

d. Standing in tank moving over rough terrain: The tank commander and occasionally the gunner or loader may stand for long periods of time in a moving tank. The work consists of standing, balancing and holding on.

The tests were conducted in the M4A3, M5 and M24 tanks over very rough ground.

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* This figure is obtained by subtracting the resting metabolism of the subjects used in the test from the total Cals/hr, rather than subtracting the average resting metabolism of the entire group. The same procedure is used subsequently in reporting each test.

Average results of 12 tests: (4 tests in each tank)

CALS/HR	CALS/M^2/HR	CALS/KG	CALS ABOVE RESTING
191	105	2.8	101

No. of subjects: 4 Test period: 6-8 mins.

e. Machine gun: Operation of the bow machine gun is an occasional activity usually of short duration. The chief work in firing consists in holding a steady body position while aiming the gun. Of more significant caloric requirement are accessory factors of loading, reloading, recocking and clearing a jammed gun.

In the present tests the bow machine gunner inserted a 250 round belt passed to him by the driver. He fired on a target at a rate of 100 rounds per minute in a series of short bursts. At the end of one minute he removed this belt and reinserted a second 250 round belt and continued firing for a total period of three minutes. During firing he recocked the gun three times.

Average results of two tests:

CALS/HR	CALS/M^2/HR	CALS/KG	CALS ABOVE RESTING
160	85	2.2	55

No. of subjects: 2 Test period: 8 mins.

f. Driving the tank M4A3:

(1) Easiest conditions: Tanks may be driven for long periods of time over hard surfaced roads. The driver's activity consists of attention to the road and minimal steering adjustments.

The subjects drove an open tank over a smooth concrete road. There were several gradual curves but no sharp turns, and no shifting or braking was necessary.

Average results of three tests:

CALS/HR	CALS/M^2/HR	CALS/KG	CALS ABOVE RESTING
140	75	2.0	50

No. of subjects: 3 Test period: 8 mins.

(2) Intermediate conditions: A fair proportion of tank driving is over unimproved roads. The driver's work consists of close attention to the road, frequent

turns and occasional shifts and braking.

In these tests the subjects drove a buttoned tank over a narrow dirt road with many curves and occasional sharp turns. In one direction the road was steadily downhill requiring braking and occasional shifts; in the opposite direction more frequent shifts were necessary. Values were approximately the same for both conditions.

Average results of 4 tests:

CALS/HR	CALS/M^2/HR	CALS/KG	CALS ABOVE RESTING
170	80	2.5	90

No. of subjects: 3 Test period: 5-7 mins.

(3) Difficult conditions: Cross country driving is the most difficult and makes up the greatest part of combat driving. The work load entailed will depend largely on the terrain. The driver's activity consists of frequent braking, shifting and turning. The driver must hold a more or less constant body position despite bumps in order to see the periscope and operate the controls.

In all tests the tank was buttoned. Two types of cross country terrain were used:

(a) Course A: The ground was rolling with several 5-10% grades. The course was moderately rough, muddy and very tortuous. In a 5-minute period the equivalent of nine right angle turns and nine shifts either up or down were necessary.

Average of 8 tests:

CALS/HR	CALS/M^2/HR	CALS/KG	CALS ABOVE RESTING
228	119	3.0	141

No. of subjects: 5 Test period: 11-40 mins.

(b) Course B: The ground was dry and in places very rough. The turns and shifts were of the same frequency as in the previous test, but there was a succession of steep hills and gullies with grades of 20-25%. The higher work rate was probably due to the considerable and prolonged effort of braking on steep hills.

Average results of 6 tests:

CALS/HR	CALS/M^2/HR	CALS/KG	CALS ABOVE RESTING
289	154	4.2	198

No. of subjects: 3 Test period: 7-8 mins.

Average results of 14 tests on both terrain conditions:

CALS/HR	CALS/M^2/HR	CALS/KG	CALS ABOVE RESTING
254	134	3.6	165

No. of subjects: 8 Test period: 7-40 mins.

g. Driving the tank M5: The M5 which is lighter in construction and smaller in size can move faster and negotiate more difficult terrain than most heavier tanks. However, the tank has less operating space for the driver and gives a rougher ride. The driving control is essentially the same as in the M4A3 except that the gear shift is semi-automatic.

The buttoned tank was driven over the difficult cross country terrain of course B.

Average results of 8 tests:

CALS/HR	CALS/M^2/HR	CALS/KG	CALS ABOVE RESTING
286	157	4.2	205

No. of subjects: 4 Test period: 5-9 mins.

h. Driving the tank M24: The tank M24 is lighter and faster than the M4A3 and has a hydramatic gear shift. The suspension provides a smoother ride than any other tank studied. The buttoned tank was driven over course B.

Average results of 8 tests:

CALS/HR	CALS/M^2/HR	CALS/KG	CALS ABOVE RESTING
229	129	3.5	144

No. of subjects: 4 Test period: 6-9 mins.

i. Driving the tank T23: In the tank T23 the drive and driving controls are electrical. The control of forward and reverse motion, and braking and steering is obtained by two six-inch levers which move with a minimum of

resistance through a distance of ten inches. There is no gear shift. The tank has more maneuverability and speed than the M4A3 and a smoother ride.

The T23 was driven over course B used for previous tests. The subjects were familiar with the tank, but far less experienced than the M4A3 drivers.

Average results of 6 tests:

CALS/HR	CALS/M^2/HR	CALS/KG	CALS ABOVE RESTING
162	83	2.3	65

No. of subjects: 3 Test period: 5-10 mins.

j. Loading procedure: The firing procedure for the main gun in combat is variable, but several practices are reported to be common:

(1) A few rounds may be fired in quick succession followed by a pause in which the tank changes position or a new target is selected.

(2) Up to 30 rounds may be fired at a maximum speed from a single site.

(3) At times the tank operates as a stationary artillery piece and a great many rounds are fired at any selected rate.

(4) The tank rarely fires while in motion.

To study these different conditions would necessitate a very large ammunition expenditure, and it was not felt that dummy ammunition would give accurate rates. The study was therefore confined to the determination of near maximum work rates which might be encountered, i.e., bursts of rapid fire.

k. Loading in the tank M4A3: The work of the loader consists of loading the round into the breech and also restoring rounds to ready racks or to the floor for future immediate accessibility. Both of these procedures involve lifting and carrying a 20-lb load in quarters imposing a considerable mechanical disadvantage.

In these tests the loader selected and loaded six rounds from the vertical ready racks immediately to his right and left, and four rounds from the horizontal floor rack beneath the gun. The rate of fire was governed by the speed of adjustment of the gun on the target. Immediately following firing the loader refilled the racks, taking the rounds from the front left sponson. In this the driver assisted by loosening the clasps.

The time of firing 10 rounds ranged from 45 to 90 seconds and the total time of work from 2 minutes, 25 seconds to 4 minutes, 40 seconds. In general higher work rates were obtained with shorter working times. (All oxygen consumptions on these and subsequent loading tests were oxygen debt

determinations. Resting values were taken immediately prior to the test.)

Average results of 6 tests:

CALS/HR	CALS/M^2/HR	CALS/KG	CALS ABOVE RESTING
540	290	7.3	440

No. of subjects: 6 Test period: 16-20 mins.

l. Loading in the M5 was not studied.

m. Loading in the tank M24: The 75mm gun M5 of the tank M24 is of lighter construction than the 75mm M3 of the tank M4A3, but has essentially the same firing properties.

Four tests were conducted in which the loader loaded ten rounds and then disposed of the empty shell cases. The rate of fire was governed by the gunner's adjustment on the target and at no time did the gunner have to wait for the loader. The firing times ranged from 58 seconds to 3 minutes, 58 seconds*, and the total working time from 2 minutes, 20 seconds to 4 minutes, 58 seconds.

Average of 4 tests:

CALS/HR	CALS/M^2/HR	CALS/KG	CALS ABOVE RESTING
424	232	6.2	334

No. of subjects: 4 Test period: 9-15 mins.

n. Loading in the T23: The T23 is fitted with the 76mm M1 gun and carries 66 rounds in compartments under the turret floor. Each round, weighing 26 lbs, must be lifted from 2 to 4 feet and usually must be carried back a short distance. The ready rack holds two rounds so that following firing there is no indication for, or possibility of, moving many rounds to the ready position as in the M4A3. The empty shell cases are large and would probably be thrown out at the earliest moment. To move rounds from the right floor stowage to the loader on the left is cumbersome and it is simpler when possible to turn the tank 180° which makes the racks immediately available.

In the tests with the M4A3 and the M24 the rate of fire was governed by the speed of adjustment of the gun on the target, but in the T23 the slower mechanics of loading determined the rate of fire.

*Delay in one test caused by a stuck clasp.

In three tests, two rounds were loaded from the ready rack and eight rounds from the floor racks. In one test the subject loaded ten rounds stacked on the floor. Immediately following firing the empty brass was thrown out of the port to the right rear. The firing times ranged from 2 minutes, 42 seconds to 3 minutes, 35 seconds and the total working times from 3 minutes, 32 seconds to 4 minutes, 58 seconds.

Average results of 4 tests:

CALS/HR	CALS/M^2/HR	CALS/KG	CALS ABOVE RESTING
534	293	7.9	439

No. of subjects: 4 Test period: 18-22 mins.

m. Moving 75mm rounds in the M4A3: The loader has 12 rounds which are immediately available for rapid fire, and 24 more which he can obtain from the floor rack and the front left sponson. Of the remaining 62 rounds, 32 are carried in two right turret racks and are readily available only to the gunner, and 30 are under the turret basket and readily available only to the assistant driver. These racks are awkwardly placed and the extraction of rounds slow.

Two tests were conducted in which the gunner passed rounds from his sponsons to the loader.

The work of the assistant driver in obtaining and passing rounds from his racks would presumably be of the same order of magnitude.

Results of 2 tests:

SUBJECT NO.	CALS/HR	CALS/M^2/HR	CALS/KG	CALS ABOVE RESTING
XIII	283	166	4.6	194
XV	344	174	4.3	264
MEAN	314	170	4.5	229

No. of subjects: 2 Test period: 6-7 mins

6. Maintenance and servicing:

At the close of a period of active combat many tasks remain for the tank crew. The vehicle must be serviced and prepared for subsequent action. Four duties are outstanding: (1) First echelon inspection and maintenance, exclusive of refuelling; (2) refuelling, usually by means of five gallon gasoline containers; (3) gun cleaning*; (4) ammunition stowage. Other special requirements will always appear in addition to these. Under combat conditions this work may be performed in poor illumination, under possibly adverse weather conditions and usually under stress of fatigue and nervous strain.

The work rate for some of these duties was estimated for the tank M4A3.

*Gun cleaning is frequently omitted

a. First echelon inspection and maintenance: Tests were conducted in which the subject followed the routine of inspection of the vehicle, examining the tracks, engine, fuel and water supply and the interior of the turret. Several minor adjustments were made in each test. The energy requirement arises chiefly from climbing in and out of the tank and lifting heavy hatches. Quite severe work might be occasionally encountered in making minor repairs.

Results of 2 tests:

SUBJECT NO.	CALS/HR	CALS/M^2/HR	CALS/KG	CALS ABOVE RESTING
XIII	281	164	4.6	192
XVI	386	202	5.4	277
MEAN	334	183	5.0	235

No. of subjects: 2 Test period : 6 mins.

b. Refuelling: The work of refuelling was not tested.

c. Gun Cleaning: The work of cleaning the 75mm gun consists of working a brush or rags back and forth against moderate to severe resistance through a distance of about eight feet, holding the rammer at shoulder or head height in a mechanically disadvantageous position.

The subjects cleaned first with the standard wire bore brush and then with rags to remove excess oil. Each was assisted by fellow crew members as is the usual practice.

Results of 2 tests:

SUBJECT NO.	CALS/HR	CALS/M^2/HR	CALS/KG	CALS ABOVE RESTING
XIV	344	200	5.5	260
XV	361	183	4.6	281
MEAN	353	192	5.1	271

No. of subjects: 2 Test period: 4 mins.

d. Ammunition stowage: A tank may often fire a large fraction of its ammunition load and not infrequently may expend several loads in a single day of combat. It is a common practice for a tank to take on all possible ammunition at any one time and to stow extra rounds loosely on the turret floor. In this manner the total stowage may reach 130 rounds*.

*Verbal reports from combat theatres.

Loading the tank is done manually, moving the rounds from a stock pile into the tank by a relay system as described below in the tests. If 100 rounds are stowed a total weight of 1 ton must be moved in individual units of 20 lbs.

The tests were divided into three parts:

(1) The subject carried two rounds at a time from a stock pile twenty feet from the tank and handed the rounds to a man on the tank*.

(2) The subject standing on the tank received two rounds and handed one or both to a man in the turret. If this man could not dispose of the rounds quickly enough the subject piled extra rounds at the base of the turret.

(3) The subject standing in the turret took individual rounds from one man standing on the tank and passed them to a second man inside the turret who stowed them.

An average of eight rounds per minute was stowed by this procedure.

Mean results of each test:

TEST NO.	CALS/HR	CALS/M^2/HR	CALS/KG	CALS ABOVE RESTING
1	566	335	9.2	481
2	475	263	7.7	390
3	256	152	4.2	172
MEAN	432	250	7.0	348

No. of subjects: 3   No. of tests: 6   Test period: 3 mins.

7. Limitations of data:

The work rate for any task within tanks varies with the manner and speed of performance and with the individual worker himself, depending on his size and strength. Charts 1,2,3 and 4 show the considerable variation in results encountered in these tests. Calculation in terms of Cals/m^2/hr or Cals/kg gives only slightly better correlation of results than in terms of Cals/hr, reflecting in addition to the above mentioned variables, variation in the task itself. For example, a driver will not duplicate precisely the

* Regulations call for carrying rounds singly to minimize the hazards of ammunition handling. However, where speed and economy of effort take precedence, two or more rounds are carried at a time.

shifts, turns and speed of another driver over the same course, and furthermore, each passage of the tank alters the terrain to some extent rendering it more or less easily negotiable. Finally, the tasks selected for study are limited in number and arbitrarily selected from a host of possible tasks.

Because of the considerations the results express only the order of magnitude of actual work rates. They may serve as guides for the estimate of the work rate of any specific task.

APPENDIX B

DISCUSSION:

This investigation was undertaken with two purposes in mind. The first was to obtain estimates of the caloric work rate of individual tank crew members, and the second to obtain comparative values for the same task in tanks of different design. It was hoped that such data would find application in two problems, (1) the design of tanks for minimum crew fatigue under all operating conditions and (2) the heat load of tank crews in hot climates.

1. The relation of work rate to mechanical efficiency of operation and to crew fatigue:

Although fatigue and its genesis are poorly understood, it is evident that the work rate is not always the most important factor. The measurement of oxygen consumption in these tests measures the energy output of the entire body and does not necessarily demonstrate work of small muscle groups which may be intense and highly fatiguing. Furthermore, there are many examples of high work rates maintained for long hours with no decline in physical effectiveness. The work rates reported in this study should not be a burden to the well conditioned soldier provided the conditions under which he works are good. But in combat, conditions are generally poor, and the effects of mental strain, lack of sleep, cold, heat, dust, inadequate rations and insufficient water are often encountered. The work rate of tank crews may at such times constitute a deleterious load. It is in combat that fatigue is least desirable, and it is there that lowered crew energy requirements may bring increased effectiveness.

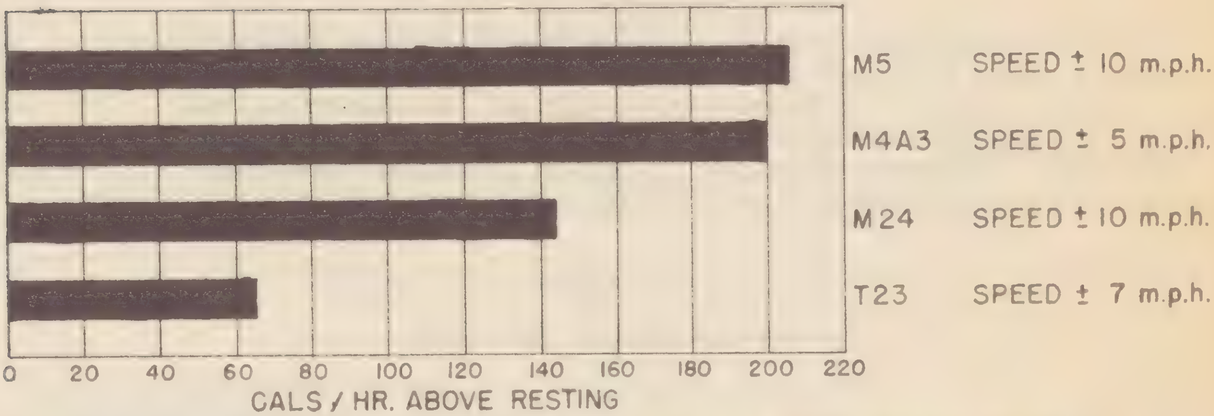
In these studies the changes in design that have lowered the crew work rate have not hampered the operation of the vehicle. The increased ease of moving the braking levers and the automatic transmission have allowed the majority of drivers, at lower energy cost, to obtain as great, or greater flexibility of tank performance. An economy of movement has accompanied a low work expenditure for the loader and has permitted rapid performance. The reduction of effort to maintain equilibrium in a moving tank has permitted crew members to carry on all duties more effectively.

a. Comparison of the same task in tanks of different design:

(1) Driver: The effort needed to operate the gear shift and braking levers is the greatest contribution to the total work load and its virtual elimination in the T23 has caused a striking fall in work rate. In the M5 with a hydramatic (semi-automatic) gear shift, the work rate appears the same as for the M4A3, but it should be remembered that in the M5 the driving was done at a greater speed, the ride was rougher, and the operating space for the driver was less. The difference in work rate between

the M5 and M24 probably reflects the smoother riding qualities, the increased operating space and the better positioning of the levers in the latter tank. (See Chart No. 5).

CHART 5
DRIVING WORK RATES



(2) Assistant driver: The dual driving controls permit the assistant driver to share the driver's work burden as well as to provide the safety of alternate controls in event of casualty.

(3) Loader: The rate of loading depends on the ease of handling the rounds and their accessibility. The M24 stows all 75mm rounds under the turret floor in bins immediately below the breech. The cramped space for the loader, with only 50 inches between turret floor and ceiling, at first glance appears to handicap his movement but actually operates to bring the bins nearer the breech and shortens the distance he must lift the round. The loader, kneeling toward the rear, with a simple efficient movement can insert the round in the breech, and much faster loading rates than here recorded are easily possible. In the T23 the heavier, longer 76mm rounds are stowed in essentially the same manner, but are more cumbersome to handle. The increased space and deeper bins make the lift and carry of the round greater and prevent the subject, at times, from maintaining a single body position. These factors contribute to the high working rate and slow loading rate of the T23 tests. The loaders were not able to keep pace with the gunner in the T23, but could easily do so in the M24 and M4A3. In the M4A3 the distance from ready rack to breech is the shortest and the lift the least. The loader remains seated and rapid loading is possible.

The M24 and T23 stow less rounds than the M4A3, but have the great advantage of decreased fire hazard. However, in combat

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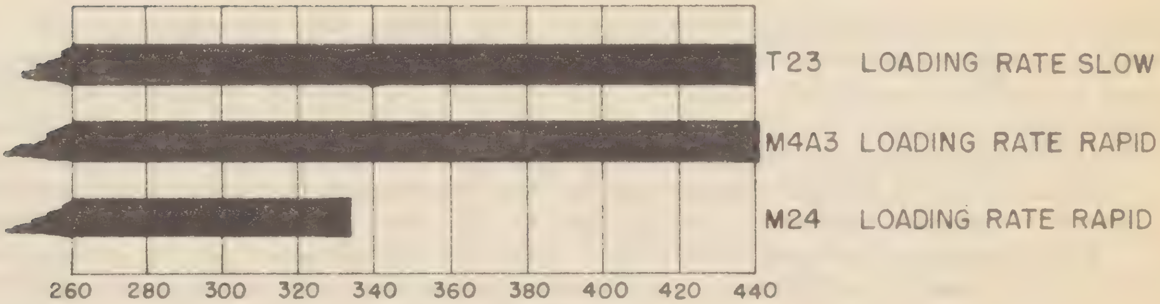
even the M4A3 crews often carry extra rounds stowed loose on the floor and elsewhere to increase their total supply. In one test in the T23 loading rounds stacked on the floor permitted faster loading with less energy output. The temptation then in the M24 and T23 to carry loose rounds would be great and would to some extent vitiate the safety of the orthodox system.

The M4A3 suffers from dispersion of round stowage. It is always necessary to replace rounds in the ready racks which is cumbersome and increases the work of the loader greatly. In the M24 and T23, at least 50% of racks are always immediately available, moving of rounds is less often indicated and when necessary more easily done. (See Chart No. 6).

CHART 6

LOADING WORK RATES



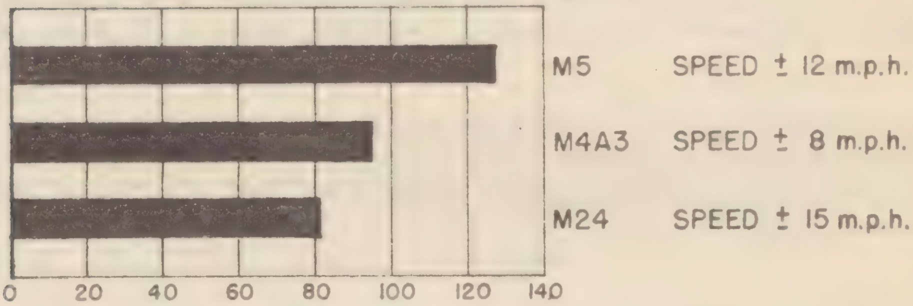
(4) Tank gunner: There seems to be little difference between the types of tank studied with relation to the work of the gunner.

(5) Tank commander: A smoothly riding tank should cause less fatigue at all times than a roughly riding tank, and performing any duties within the moving tank whether driving, firing or loading will be easier.

Comparative work rates of the same four men, standing in the commander's position in three different tanks moving over the same terrain, measure essentially the effort of holding on and balancing and, indirectly, the roughness of the ride. The rates agree entirely with the subjective reactions of the men as to comparative smoothness of ride. A definite difference is seen and indicates the effectiveness of an improved suspension system. Although only the commander was studied, the same effect should apply to all crew members and contribute to the total work rate and to the ease or difficulty of their performance of duty. It is

furthermore of interest to note that the M24 could be driven faster over rough ground than the M5 though the latter has a higher top speed. (See Chart No. 7).

CHART 7
STANDING WORK RATES



b. Maintenance and servicing: Comparative work rates were not obtained, but there is no reason to anticipate any pronounced differences between the tanks studied. The results, however, indicate clearly that the tanker still has much work to do after leaving the field of combat. Estimates of time for maintenance and servicing are about two hours nightly*. All duties studied yielded rates of about the same order of magnitude and if an average figure of 350 Cals/hr is accepted per man for two hours, it is equivalent in energy demand to seven miles of march in the same period of time. This load may be important as a contribution to fatigue when operating conditions are difficult and particularly when sleep is lacking.

2. The heat load of tank crews in hot climates:

The physiological mechanism for dissipation of body heat is inadequate when certain ranges of environmental heat and humidity are reached. This leads to impairment of the physical and mental powers of the individual and thereby decreases his effectiveness. Several aspects of this problem which apply to tank crews are as follows:

a. A soldier exposed to an excessive heat load undergoes marked physiological alterations leading finally to collapse or heat exhaustion. Tank crews in particular are exposed to this hazard because the severity of their internal vehicular environment as regards temperature and humidity may considerably exceed the severity of the external environment or prevailing climate, (refs. 1,5). Heat exhaustion has probably occurred in certain Pacific theatre operations and has constituted a handicap to military operations**.

* Estimate of tank crew members returned from combat

**It is difficult to know the incidence of heat exhaustion and impairment of crew efficiency due to heat and humidity from combat reports. Observations have been meagre and confusion has existed as to the contribution of other factors such as gun fumes, battle strain and general fatigue to the production of casualties in tank operations, (ref. 2). Numerous field reports testify to the adverse effects of heat and humidity on crew performance, (refs. 3,4,5,6,7).

b. Of greater practical importance is the more common and marked impairment of efficiency and morale which occurs before actual heat exhaustion supervenes (refs. 2 thru 7). Because of excessive heat, tanks have occasionally had to operate in relays of short duration (refs. 2, 8).

c. A single crew member operating near the upper limits of thermal tolerance may require 2 quarts of water per hour (refs. 7, 9), or an entire tank crew may need 10 or more gallons for four hours' operation. This produces a problem in water stowage.

d. Any impairment of ventilation within the tank increases the overall thermal load of the crew. Fighting in an idling or slowly moving tank is very frequent in certain Pacific theatre operations and ventilation is then very poor. Sealage for gas protection and for wading diminishes ventilation and accentuates the problems already mentioned.

Attempts have been made to achieve greater climatic heat tolerance by improving the ventilation within tanks or by cooling the crew members directly, and, insofar as these efforts have been successful, they have been beneficial. The principle involved has been to increase the loss of body heat. However, deceased production of body heat should operate to the same purpose and experimental evidence is at hand to prove the value of this principle. Near the upper limits of tolerance to heat and humidity small increments of heat production, i.e. work rate, have been shown to have a markedly deleterious effect (ref. 9). Measures that lessen the work rates of tank crews will allow higher limits of heat and humidity.

In evaluating the data of work rates presented, several factors are important. (1) The effect of work rate on the impairment of military effectiveness in hot climates, depends not only on its magnitude, but also on its duration. High rates are poorly tolerated even for short duration and moderate rates poorly tolerated for long duration. (2) An additional energy load common to all tank crew members and not shown in these tests results from nervous strain of combat. The mechanism of this is uncertain, but may consist in part of a generalized increase in muscle tension, an increase in the speed and vigor of muscle movements, and an increase in the number of accessory movements. Basal metabolism in certain cases is known to be raised by 10 to 35 Cals/hr (ref. 10), and such increases may be greater during muscular activity. (3) An added energy load is produced by a variety of housekeeping jobs. Among these are disposal of empty brass, opening and closing of hatches, periscope adjustment, instrument checking and numerous other duties of low caloric demand.

An effort has been made to estimate work rates (or heat production rates) taking the basic work rate plus additions for nervous strain and for housekeeping. Twenty Cals/hr are added for nervous strain and 10 Cals/hr for housekeeping. Furthermore these corrected rates are tabulated for definite durations of time, namely 5, 10, 20, or 60 minutes. For each time period a likely series of activities has been postulated and the rate calculated.*

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* The rates for the tank M4A3 are calculated in a different manner but are in essential agreement with those reported by the Military Personnel Research Committee of the British Medical Research Council, July 1944 (confidential).

For example, the loading rate for the 5-minute interval is calculated on the basis of 15 rounds loaded, for the 10-minute interval on the basis of 20 rounds loaded, and for 60 minutes on the basis of 50 rounds loaded. Certain activities, notably driving, obviously could continue at near maximum rates for periods of time much greater than 60 minutes. Maintenance and servicing have not been included.

The rates are tabulated in Chart No. 8. The figures represent heat production for situations which commonly occur* and are near full activity. These rates are doubtless occasionally exceeded, but any evaluation of the thermal load of crews should include endogenous heat production rates of at least these magnitudes. Comparison of the values for different tank models reflects the change that tank design has produced on work rate.

SUMMARY:

The order of magnitude of work rates for crew members in the tanks M4A3, M5, M24 and T23 has been determined. Changes already accomplished in design have reduced these work rates in certain tanks. The greater ease and efficiency of crew operation thereby attained will probably result in lessened crew fatigue, particularly when the associated stress and strain is great as is generally the case in combat. Furthermore, the work rates determined constitute a significant contribution to the heat load of crews operating in tropical climates and any measures that diminish the rates will allow greater climatic heat tolerance and improve military effectiveness in that regard. In no case studied was any decrease in mechanical operating efficiency noted as a result of measures reducing crew work rates. It has been recommended that agencies and individuals concerned in tank design promote efforts to reduce work rates, and that any agencies or individuals concerned with the design of tank crew equipment, particularly clothing, take cognizance of the contribution of work rate to the heat load of crews.

*Situations postulated have been checked with crew members returned from overseas for their likelihood of occurrence.

CHART #8

ESTIMATE OF RATES OF WORK FOR NEAR FULL ACTIVITY OVER DIFFERENT PERIODS OF TIME

(See text for detailed explanation)

CREW MEMBER	CHARACTER OF WORK	TANK MODEL	WORK RATE IN CALS/HR 5 Mins	10 Mins	20 Mins	60 Mins
DRIVER	Driving over difficult cross country terrain	M4A3	320	320	320	300
	" " " " " "	M5	320	320	320	300
	" " " " " "	M24	260	260	260	240
	" " " " " "	T23	190	190	190	170
ASS'T DRIVER*	Passing ammo. Machine gun oper.in moving tank	M4A3	340	280	220	190
	Machine gun operation in moving tank.	M5	260	230	215	205
	" " " " " "	M24	210	180	165	155
	" " " " " "	T23	215	185	170	160
COMMANDER	Standing, moving over rough terrain.	M4A3	220	220	220	200
	" " " " "	M5	250	250	250	230
	" " " " "	M24	200	200	200	180
	" " " " "	T23	210	210	210	190
GUNNER‡	Ammo. passing. Seated in moving tank	M4A3	340	270	235	220
	" " " "	M5	300	250	220	220
	Ammo. passing. " " " "	M24	310	230	190	180
	" " " " " "	T23	340	250	200	185
LOADER	Loading (15 rds/5 mins;20 rds/10 mins; -	M4A3	580	450	380	285
	" 30 rds/20 mins; 50 rds/60 mins)	M5				
	" " "	M24	455	350	280	220
	" " "	T23	565	480	390	285

* May assume work of driver in M5, M24 and T23

‡ In M5 also tank commander

Incl. #3

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Incl. #1

CHART #1

WORK RATES - TANK M4A3

SUBJECT NO.	EXPERIENCE	BASAL METABOLISM Cals Hr	Cals M^2 Hr.	Cals kg	% of normal	RESTING SEATED-QUIET Cals Hr	Cals M^2 Hr	Cals kg	RESTING-MOVING TANK SEATED-PERISCOPE OBSERVER Cals Hr	Cals M^2 Hr.	Cals kg	Cals Above Resting	MACHINE GUN LOAD-FIRE-RECOCK-RELOAD Cals Hr	Cals M^2 Hr	Cals kg	Cals Above Resting
I	Exp. Driver					76	43	1.1								
						80	42	1.1								
II	Inexp. Driver					81	43	1.1								
						80	42	1.1								
III	Inexp. Driver	71	34	0.7	-10	122	58	1.3								
	Exp. Loader	74	35	0.8	-7	120	57	1.3								
IV	Inexp. Driver	61	35	0.9	-6	70	39	1.0								
	Inexp. Loader	65	37	0.9	0	85	48	1.2								
V	Exp. Driver	73	33	1.0	-2	67	35	0.9								
	Inexp. Loader	66	34	0.9	-11	68	35	0.9								
VI	Exp. Driver	61	34	1.0	-10	76	42	1.2	90	50	1.4	6				
		63	35	1.0	-7	92	51	1.5								
VII	Exp. Driver	66	36	1.0	-5	78	43	1.2	126	69	1.9	42				
		65	36	1.0	-6	89	49	1.4	108	59	1.7	24				
VIII	Exp. Driver	71	36	0.9	-7	97	49	1.3	136	69	1.8	31				
		71	36	0.9	-6	113	57	1.5								
IX	Exp. Loader	65	37	1.0	+2	97	56	1.5								
X	Exp. Loader	71	39	1.0	+1	99	55	1.3					160	88	2.2	61
XI	Exp. Loader	74	38	1.0	-1	108	56	1.5					161	84	2.2	53
MEANS		68	36	0.9	-5	90	50	1.3	120	60	1.7	25	160	85	2.2	55

Incl. #5

CHART #1 (Cont'd)

WORK RATES - TANK M4A3 (CONT'D)

SUBJECT NO.	DRIVING-EASY Open - Paved Road				DRIVING-INTERMEDIATE Buttoned-Curving Dirt Road				DRIVING-DIFFICULT Course A: Heavy Mud Course B: Steep Hills				LOADING 10 r'ds fired 10 r'ds replaced				
	Cals Hr	Cals M^2 Hr	Cals kg	Cals Above Resting	Cals Hr	Cals M^2 Hr	Cals kg	Cals Above Resting	Cals Hr	Cals M^2 Hr	Cals kg	Cals Above Resting	Firing Time Total Time	Cals Hr	Cals M^2 Hr	Cals kg	Cals Above Resting
I					177 172	63 62	2.6 2.5		176	108	2.6	98					
II									239	123	3.3	158					
III								Course A	256 290	120 135	2.7 3.1	135 169	F.T. 1'53" T.T. 3'43"	547	257	5.8	426
IV									241 198	135 111	3.5 2.9	164 121	F.T. 2'00" T.T. 4'40"	397	223	5.8	320
V					183	94	2.4		198 224	102 115	2.6 3.0	130 156	F.T. 1'13" T.T. 3'39"	410	212	5.5	342
VI	116	64	1.8	32	157	86	2.5		217 233	120 129	3.4 3.7	133 149					
VII	116	64	1.8	32				Course B	316 263	174 145	4.9 4.1	232 179					
VIII	179	91	2.4	74					348 358	176 181	4.6 4.7	243 253					
IX													F.T. 45" T.T. 2'25"	651	380	10.0	554
X													F.T. 50" T.T. 3'04"	560	310	7.6	461
XI													F.T. 1'14" T.T. 3'04"	660	340	8.9	552
MEANS	140	75	2.0	50	170	80	2.5	90	254 A 228 B 289	134 119 154	3.5 3.0 4.2	165 141 198		540	290	7.3	440

Incl. #5

CHART #2

WORK RATES - TANK M24 AND TANK M5

Subject No. / Experience	BASAL METABOLISM				RESTING SEATED-QUIET			DRIVING M24 DIFFICULT COURSE B				LOADING M24 10 RDS - RAPID FIRE					DRIVING M5 COURSE B			
	Cals Hr	Cals M^2 Hr	Cals kg	% of normal	Cals Hr	Cals M^2 Hr	Cals kg	Cals Hr	Cals M^2 Hr	Cals kg	Cals Above Rest.	Firing Time / Working Time	Cals Hr	Cals M^2 Hr	Cals kg	Cals Above Rest.	Cals Hr	Cals M^2 Hr	Cals kg	Cals Above Rest.
XII	66	40	1.1	+5	83	50	1.4	201	121	3.3	116									
Exp. Driv.					86	52	1.4	188	113	3.1	103									
								199	116	3.2	110									
XIII	70	41	1.1	+7	82	48	1.3	219	128	3.5	130	F.T. 0'58" W.T. 2'20"	388	227	6.3	299	258	150	4.2	169
Exp. Driv.					95	56	1.5	242	141	3.9	153						244	143	4.0	155
XIV	74	43	1.2	+12	82	48	1.3	260	151	4.1	176	F.T. 1'39" W.T. 2'40"	437	254	6.9	353	296	172	4.7	212
Exp. Driv.					85	49	1.4	233	135	3.7	149						264	154	4.2	180
XV	80	41	1.0	+11	79	40	1.0	257	130	3.2	177	F.T. 3'58" W.T. 4'58"	* 500	* 254	* 6.3	* 420	285	145	3.6	205
Inexp. Driv.					81	41	1.0	260	131	3.3	180						272	138	3.4	192
XVI	74	39	1.0	+2	106	56	1.5					F.T. 1'54" W.T. 3'20"	371	194	5.1	262	315	165	4.4	206
Exp. Driv.					111	58	1.5										354	185	4.9	243
MEANS	73	41	1.1	+7	89	50	1.3	229	129	3.5	144	F.T. 2'07" W.T. 3'20"	424	232	6.2	334	286	157	4.2	194

* Difficulty and delay because of stuck clasp.

Incl. #6

CHART #3.

WORK RATES IN TANK T23

Subject No. EXPERIENCE	BASAL METABOLISM				RESTING SEATED-QUIET			DRIVING DIFFICULT-COURSE B				LOADING 10 RDS - RAPID FIRE				
	Cals Hr	Cals M^2 Hr	Cals kg	% of Normal	Cals Hr	Cals M^2	Cals kg Hr	Cals Hr	Cals M^2 Hr	Cals kg	Cals Above Rest.	Firing T. Working T.	Cals Hr	Cals M^2 Hr.	Cals kg	Cals Above Rest.
XVII Exp. Driv.	72	37	1.0	-3	101	52	1.4	135	70	1.8	34	F.T. 2'42" W.T. 3'37"	660	340	9.0	559
Inexp. Load								132	68	1.8	31					
XVIII Exp. Driv.	61	36	1.0	-5	93	54	1.5	121	71	2.0	40	F.T. 2'58" W.T. 3'50"	540	310	8.7	449
Exp. Load.					88	51	1.4	124	72	2.0	33	F.T. 2'45" W.T. 3'32"	* 466	* 270	* 7.5	* 375
VIII Inexp. Driv.	72	36	0.9	-5	97	49	1.3	‡ 233	109	3.1	128					
	71	36	0.9	-6	113	57	1.5	‡ 226	107	3.0	121					
XIX Exp. Load.	63	34	0.9	-8	90	49	1.2					F.T. 3'35" W.T. 4'58"	469	250	6.3	374
					99	53	1.3									
MEANS	68	36	0.9	-5	97	52	1.4	162	83	2.3	65	F.T. 3'00" W.T. 3'59"	534	293	7.9	439

* Rounds loaded from floor.

‡ Subject in addition to inexperience showed consistently high rates for all activities tested.

CHART #4

COMPARATIVE WORK RATES OF STANDING												
SUBJECT NO.	TANK M5 ROUGH - COURSE C				TANK M4A3 ROUGH - COURSE C				TANK M24 ROUGH - COURSE C			
	Cals Hr	Cals M^2 Hr.	Cals kg	Cals Above Rest.	Cals Hr	Cals M^2 Hr	Cals kg	Cals Above Rest.	Cals Hr	Cals M^2 Hr	Cals kg	Cals Above Rest.
XIV	195	113	3.1	111	147	86	2.3	63	178	104	2.6	94
XIII	246	145	4.0	157	193	113	3.1	104	150	88	2.4	61
XV	226	115	2.8	146	197	100	2.5	117	188	96	2.4	108
XVI	204	107	2.8	95	203	105	2.8	94	168	88	2.3	59
MEANS	218	120	3.2	127	185	101	2.7	95	171	94	2.4	81

Incl. #8